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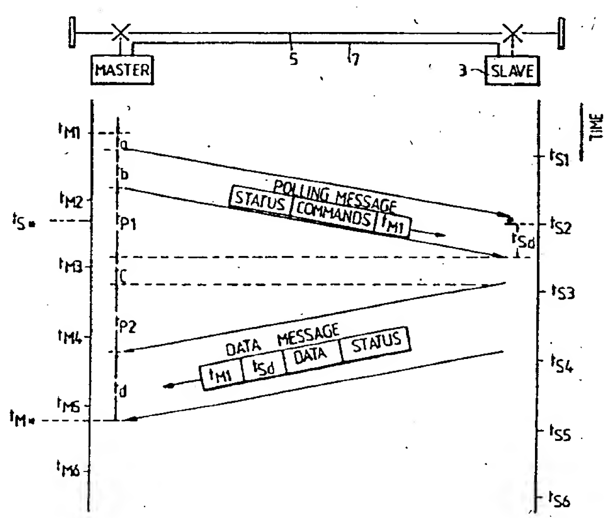
(54) Relays.

(57) A differential relay includes two apparatus (1, 3) each associated with a different monitoring point on the line (5) being protected by the relay. Each apparatus includes means for deriving digital data representative of the current monitored at the respective point, at time intervals defined by a clock within the apparatus. The two points are linked by a digital data communication channel (7), and information transmitted between the two points is used to compute digital data for the two points at substantially the same time, from digital data derived at different instants at the two points.



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Relays

This invention relates to relays for protecting an electrical power transmission system comprising a two or more ended electrical feeder. In particular the invention relates to differential relays which operate to protect the system when the difference between the value of an electrical quantity, usually current, monitored at two or more different points on the feeder, exceeds a predetermined amount.

In recent years differential relays have been developed which use digital data transmission to transmit the necessary data regarding the monitored electrical quantities between the monitoring points on the feeder. Such differential relays are generally more reliable and faster than relays using analog transmission. Differential relays using digital data transmission do, however, suffer the disadvantage that as digital data, unlike continuous analog signals, represent the value of the monitored electrical quantity at discrete time intervals, it is necessary that some form of synchronisation be provided so that digital data collected at different points on the feeder can be aligned to the same time instant. Known differential relays using digital data transmission solve this synchronisation problem by providing an external radio clock, but this leads to additional cost and complexity, and furthermore a suitable radio clock may

not be available to all users of the power transmission system. Other known differential relays using digital data transmission solve the synchronisation problem by using a clock signal derived from the communication multiplexing equipment, but this approach suffers the problem that the derivation of the clock signal is very dependent on the actual design of the communication multiplexing equipment, the network configuration and the control hierarchy adapted: as the relay would have to work with a variety of communication equipment, the cost for developing different clock interfaces could be prohibitive. Furthermore, a clock source may not be available if the relay is to be used over a direct non-multiplexing link.

In U. K. Patent Application No. GB 2072974A there is described a differential relay using digital data transmission in which independent clocks are provided at the monitoring points along the line to be protected, the clocks defining the time intervals at which electrical data is measured at the monitoring points. Digital data relating to the current measured at a local monitoring point is transmitted to a remote monitoring point and stored in a first memory, while digital data relating to the current measured at the remote monitoring point is stored in a second memory. A shift register is arranged to shift through the data in the first memory to correct the data therein by a factor corresponding to the transmission time of the data collected at the local monitoring point between the local and remote monitoring points. The data collected at

sampling times $t_1 + \alpha$, $t_2 + \alpha$, $t_3 + \alpha$ -- at the remote monitoring point is then compared with the correct data collected at sampling times t_1, t_2, t_3 -- at the local monitoring point, where α is the time interval between the sampling times at the two points, to determine whether the relay is to operate.

Such a relay suffers the disadvantages however that in order to achieve a reasonable amount of accuracy, the sampling time interval α must be small and so a very high sampling rate must be used for the derivation of data at the monitoring point. The data transmission time must also be known and remain constant during operation.

It is an object of the present invention to provide a differential relay using digital data transmission, with independent clocks defining the time intervals at which electrical data is measured at the monitoring points capable of operation at lower sampling rates.

According to the present invention a differential relay operative to protect an electrical feeder is an electrical power transmission system dependent on the differences in an electrical quantity monitored at different monitoring points on the feeder comprises: a respective apparatus including means for deriving digital data representative of the value of the electrical quantity at the point, at time intervals defined by a respective clock within the apparatus; a digital data communication channel linking the monitoring points; and means for transmitting through the communication channel a polling message from a first said apparatus located at a first monitoring point, to a second said apparatus located at a second monitoring point, the second apparatus including means

responsive to the polling message to return a data message to the first apparatus containing an indication of the value of the digital data derived at the second point said first apparatus utilising the data message to compute digital data for the first and second points at substantially the same instant.

One differential relay in accordance with the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a graphical representation of the operating principle on the relay; and

Figure 2 illustrates the differential protection characteristics of the relay.

Referring firstly to Figure 1, the relay comprises a master apparatus 1, and a number of slave apparatus 3, situated at the other ends of a mult-ended electrical feeder 5, only one such slave apparatus 3 being shown in the figure for simplicity, each apparatus being under the control of one or more microprocessors. The master apparatus samples current signals at its end of the feeder at time intervals t_{M1}, t_{M2} etc. which are defined by a free-running clock incorporated within the master apparatus aa indicated in Figure 1. The slave apparatus samples current signals at its end of the feeder at time intervals t_{S1}, t_{S2} which also need not be identical but are defined by an independent free-running clock incorporated within the slave apparatus, the sampling times at the master and slave ends of the feeder not necessarily being coincident. The sampling times may even be at slightly different frequencies. The sampled current signals at each end of the feeder represent the instantaneous values of the three phase currents and the neutral current at the end, and may contain

unwanted d.c. offset, harmonics, and high frequency components. The master and slave apparatus thus contain means for filtering the data, and preprocessing it to a form suitable for the calculation of the magnitudes of differential and bias currents as further described hereafter.

At required times, for example after the time interval t_{M1}, the master apparatus 1 sends a polling message down a digital data communication channel indicated as 7 to the slave apparatus 3. This polling message contains a time tag corresponding to t_{M1}, and command and status information. The slave apparatus 3 responds to the polling message by returning a data message to the master apparatus, containing the polling time tag t_{M1}, the time between the most recent slave apparatus sampling and the arrival of the polling message, the most recently filtered current data sampled by the slave apparatus, and other status information. Using the send-off time of the polling message, and the arrival time of the slave data message, the master apparatus is then able to calculate the communication channel delay time, and to time align the slave data to the master data using a vector transformation technique as described hereafter. The master apparatus then operates to protect the feeder when the difference between the time aligned current values at the two ends of the feeder 5 exceeds a predetermined value.

The one-cycle window Fourier signal processing method is used to filter and preprocess the current signals measured at each end of the feeder. The algorithm for this method can be expressed as:

$$I_s = \frac{2}{N} \sum_{n=1}^{N-1} \sin n w \Delta t \cdot i_n$$

$$I_c = \frac{2}{N} \left(\frac{i_o}{2} + \frac{i_N}{2} + \sum_{n=1}^{N-1} \cos n w \Delta t \cdot i_n \right)$$

where N is the number of samples measured per cycle of the current signal in the feeder;

w is the fundamental angular frequency of the current signal;

Δt is the sampling time;

i_n is the instantaneous value of the current signal measured at time t_n

I_s is the Fourier sine integral of the current signal; and

I_c is the Fourier cosine integral of the current signal.

If the fundamental component of the current signal is I sin (wt + θ) where θ is a phase angle, then it can be shown that:-

$$I_s = I \cos \theta$$

$$I_c = I \sin \theta$$

As the phase angle θ is related to the time reference of the data window, I_s and I_c are not static, but are sinusoidal quantities. The phasor $\bar{I} = (I_s + jI_c)$ thus represents a vector rotating in an anticlockwise direction on the complex plane at the angular frequency w, from which the magnitude of the current signal i may be extrapolated.

Assuming the master apparatus decides to send a polling message to the slave apparatus at time ta after data sampling at t_{M1}, the communication interface of the master apparatus will take some time t_b to send out the whole polling message. If the transmit channel propagation delay time is t_{p1}, then the end of the polling message will have arrived at the slave apparatus at time $(t_{M1} + t_a + t_b + t_{p1})$. The returned data message, containing the polling time tag t_{M1}, the time between the slave sampling t_{S2} and the arrival of the polling message t_{sd}, the filtered I_s, I_c data last produced by the slave apparatus at time t_{S2}, and other status information will have arrived back at the master apparatus at time t_{M*} where

$$t_{M*} = (t_{M1} + t_a + t_b + t_{p1} + t_c + t_d + t_{p2})$$

where t_c is the processing time the slave apparatus takes

before it starts to send off the data message;

t_d is the time the communication interface of the slave apparatus takes to send out the whole data message; and

t_{p2} is the receive channel propagation delay.

If it is assumed that the transmit and receive channels have the same propagation delay time, i.e. $t_{p1} = t_{p2}$, as t_a, t_b, t_c and t_d are all known quantities, then the channel propagation delay time t_p may be calculated from:

$$t_{p1} = t_{p2} = t_p = (t_{M*} - (t_{M1} + t_a + t_b + t_c + t_d))/2$$

After estimating the value of t_p, the master apparatus is then able to identify the sampling time, t_{s*} of the received slave data from the expression:

$$t_{s*} = t_{M*} - (t_{sd} + t_c + t_d + t_p)$$

After identifying t_{s*}, the slave data may then be time aligned with the master data. As can be seen in Figure 1, in the particular relay being described by way of example, t_{s*} happens to be equal to t_{s2}. The master apparatus should identify, therefore, that the slave data are sampled at a time between t_{M2} and t_{M3}, so that the slave data must be aligned to these times. Alignment to both these times is required, as this allows differential protection comparison to take place on every data sample of the master apparatus, while requiring the slave apparatus to be polled for data only once every two data samples, so reducing the data bandwidth requirement.

Using a look-up table, the parameters (a+jb) required to perform a phase shift on $(I_s + jI_c)$ for the slave data, corresponding to the time $(t_{M3} - t_{S*})$ may be obtained.

The phasor value of the slave current I_{S3} at time t_{M3} may then be calculated from:

$$\begin{aligned} I_{S3} &= (I_s + jI_c)(a+jb) \\ &= (aI_s - bI_c) + j(bI_s + aI_c) \end{aligned}$$

The value of the slave current at time t_{M2} can be obtained likewise by rotating I_{S3} backward by a fixed angle corresponding to the sampling time period.

Referring now also to Figure 2, if I_A, I_B, I_C, ... are the current signals measured at ends A, B, C ... of the protected feeder, then the differential current, I_{diff}, and the through current $I_{through}$ are defined as:

$$I_{diff} = I_A + I_B + I_C + \ldots$$

$$I_{through} = |I_A| + |I_B| + |I_C| + \ldots$$

As indicated in Figure 2, a percentage biased differential protection characteristic is used for the relay, the tripping criteria being:-

$$|I_{diff}| > k\ (\ I_{through} \quad \ldots\ldots)$$

and $$|I_{diff}| > I_{th}$$

where k is the bias coefficient and

I_{th} is the minimum differential current value for trip protection.

The microprocessor incorporated in the master apparatus then calculates $|I_{diff}|$, $|I_A|$, $|I_B|$ ... from the corresponding vector components I_s, I_c using a linear approximation technique to perform the equivalent of the equality

$$|I| = \sqrt{(I_s^2 + I_c^2)}$$

so as to determine from the monitored values of current after they have been time aligned whether to operate the relay to protect the feeder.

The microprocessor may be self manipulating to vary the threshold and through current settings to produce an adaptive relay characteristic for improved sensitivity and stability.

In one particular relay in accordance with the invention adopting the ISO//CCITT's high level data link control communication protocol, for the data message, the information field will suitably contain the polling time

tag (1 byte), the slave sampling delay time t_{sd} (1 byte), I_s and I_c of the phase and neutral current signals (16 bytes), and status information (1 byte). The whole message frame, would therefore be 25 bytes long, have a protocol efficiency of 76%, and take about 3.75 ms to transmit through a single 64 kbps data channel. It will, therefore be possible to share the communication link with other signalling and telecommunication equipment. As only one data message needs to be transmitted for each two data samples, a suitable sampling rate would be 8 samples per cycle of the mains supply, the resulting average relay operating time being about 26 ms for 50Hz operation. It will be appreciated however that this performances represents a balance of operating speed, and communication requirement and does not represent the limit of the relay. Typically the relay will have sampling rates of between 400 to 800 per second, these relatively low sampling rates enabling the use of low cost electronic components in the relay. Faster operating times may be achieved by using wider bandwidth channels, whilst slower, more economical channels may be used for applications which do not required phase selection. It will be appreciated that any form of data communication channel may be used in a relay in accordance with the invention, such as fibre optic links, or conventional communication lines with adequate bandwidth. As the relay is microprocessor based however, a particular advantage of a relay in accordance with the invention is that it is easily adapted to work with different communication equipment by minor changes in the interfacing hardware.

It will also be appreciated that as the channel delay time t_p is calculated for each data poll, any changes on the communication channel are monitored, this being particularly important where the communi-

cation time is part of a switched telecommunication network.

It will also be appreciated that as the time tag t_{M1} is incorporated in both the polling message and the data message, the time tag may be used to perform the function of a random number check on the communication and processing facilities of the relay.

It will also be appreciated that whilst in the particular relay described herebefore by way of example there is a master apparatus, and a number of slave apparatus, the invention is equally applicable to master-master arrangements in which the relay can both send a poll message and respond to a polling message at the same time. Under the master-master situation, each message will act both for polling and data transmission and will contain two time tags, one from each end, status, command, data and other timing information, such as t_{sd}, t_a, t_c. The timing information t_a and t_c are required in the master-master arrangement as the delay between the arrival of a message and the return message can be variable. Whilst such a master-master arrangement may be applicable in a two or three-ended feeder system generally however, master-slave arrangements in multi-ended systems are advantageous as they lower the communications and processing requirements.

It will also be appreciated that each master or slave apparatus may, in itself include a means for back-up protection of the feeder. Thus in the event of the failure of the communication channel, or communication equipment, the protective equipment at the ends of the feeder may be given the option of staying idle or operating under a stand-alone mode as a form of back-up protection. For example the

protection equipment may operate as an overcurrent protection relay based on the local I_s, I_c values measured.

CLAIMS

1. A differential relay operative to protect an electrical feeder in an electrical power transmission system in dependence on the differences in an electrical quantity monitored at different monitoring points on the feeder comprising: a respective apparatus associated with each monitoring point, each apparatus including means for deriving digital data respresentative of the value of the electrical quantity at the point, at time intervals defined by a respective clock within the apparatus; and a digital data communication channel (7) linking the monitoring points; the relay being characterised in that it includes means for transmitting through the communication channel a polling message from a first said apparatus (1) located at a first monitoring point, to a second said apparatus (3) located at a second monitoring point, the second apparatus (3) including means responsive to the polling message to return a data message to the first apparatus (1) containing an indication of the value of the digital data dervied at the second point said first apparatus (1) utilising the data message to compute digital data for the first and second points at substantially the same instant.

2. A relay according to Claim 1 in which said data message includes an indication of the time interval between the time said value was derived and the receipt of the polling message.

3. A relay according to either of the preceding claims including means for calculating the transmission times of the polling message and the data message through the communication channel (7).

4. A relay according to Claim 3 in which the first apparatus (1) includes means for measuring the time elapsing from the transmission of the polling message to the receipt of the data message and means for measuring the transmission time from said elapsed time.

5. A relay according to any one of the preceding claims in which the polling message includes a time tag (t_{m1}) indicative of the time of derivation of digital data by the first apparatus.

6. A relay according Claim 5 in which the data message also includes the time tag (t_{m1}).

7. A relay according to Claim 6 including means for using the time tag (t_{m1}) to perform a random number check on the operation of the relay.

8. A relay according to any one of the preceding claims in which the second apparatus (3) includes filtering means effective to preprocess the digital data derived at the second point.

9. A relay according to Claim 8 in which the preprocessing is effective to remove dc and harmonic components from the digital data.

10. A relay according to Claim 9 in which the filtering means is a Fourier filtering means.

11. A relay according to any one of the preceding claims in which said computing of digital data is performed using a vector transformation technique.

12. A relay according to any one of the preceding claims wherein the digital data at the second point is derived only once for every two digital data derivations at the first point.

13. A relay according to any one of the preceding claims in which the electrical quantity is current.

14. A relay according to any one of the preceding claims in which each apparatus is microprocessor controlled.

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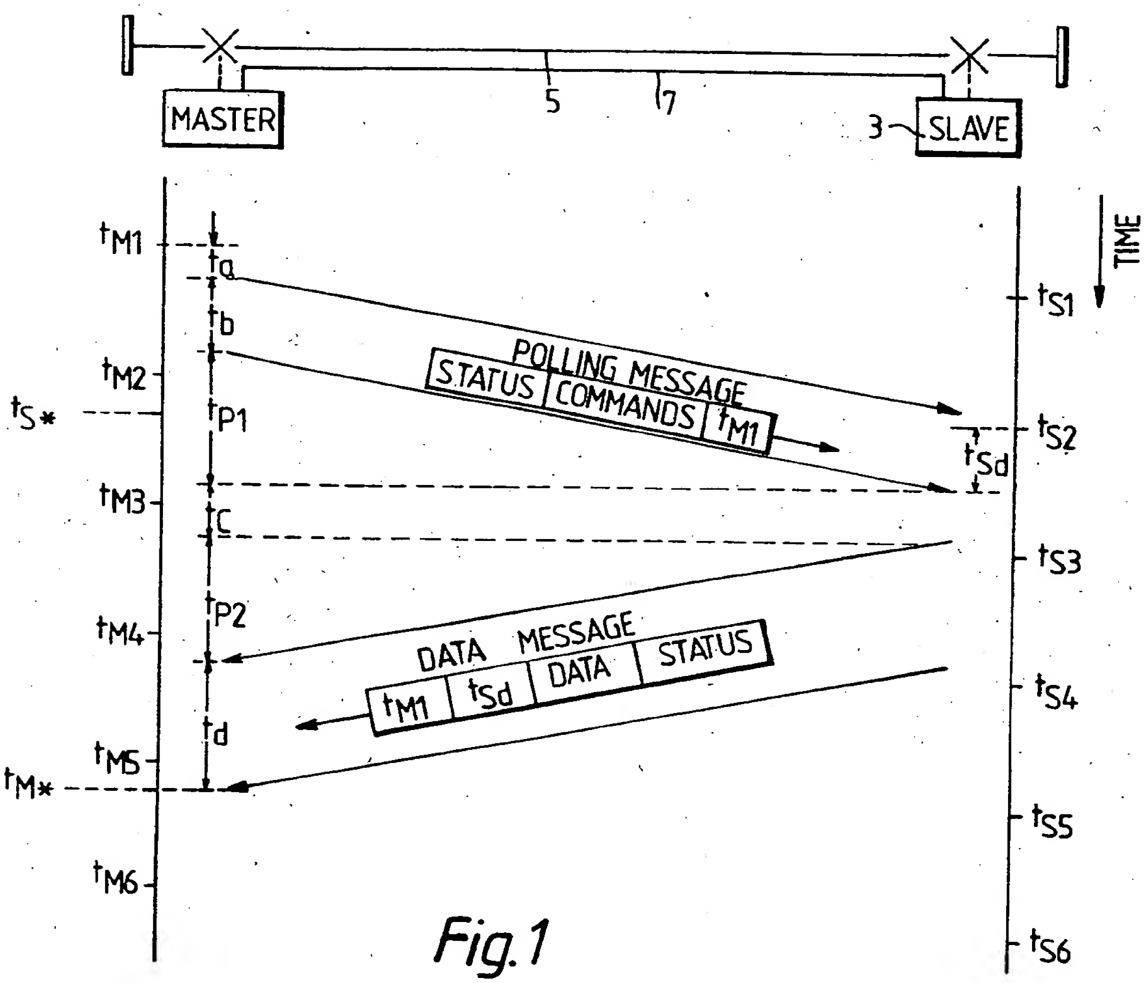

Fig.1

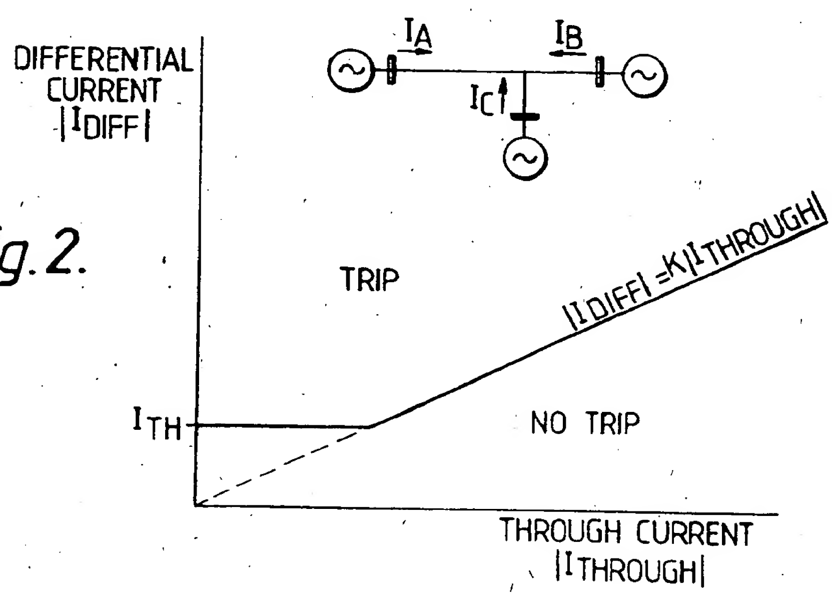

Fig.2.